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FOURTH PROGRESS REPORT

on

THE DEVELOPMENT OF A HIGH-LEVEL, DIRECTIONAL,  
UNDERWATER-SOUND SOURCE USING EXPLOSION-  
INDUCED SHOCK WAVES

to

ACOUSTICS BRANCH  
OFFICE OF NAVAL RESEARCH

Project NR 385-409, Contract Nonr 903-(00)

February 1, 1954

by

E. G. Thurston, W. H. Peake, D. Ensminger,  
H. E. Trumbull, and J. H. Duffin

B. A. Landry and R. K. Crooks,  
Division Chiefs

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February 17, 1954

Mr. W. Annis  
Head, Acoustics Branch  
Department of the Navy  
Office of Naval Research  
Washington 25, D. C.

Dear Mr. Annis:

Enclosed are six copies of the Fourth Progress Report on Contract Nonr 903-(00), entitled, "The Development of a High-Level, Directional, Underwater-Sound Source Using Explosion-Induced Shock Waves". We are distributing another fourteen copies according to your "Distribution List of Technical Reports", Battelle Memorial Institute, Contract Nonr 903-(00), NR 385-409, dated 2 December 1953.

This report covers work done between May 1, 1953, and August 1, 1953.

No experimental work was done between August 1, 1953, and January 4, 1954, pending the receipt of the contract authorizing further work.

We have already begun altering the firing mechanism of the Primacord unit and should be ready to begin experimentation in a very short time.

Sincerely yours,

*R. K. Crooks*

R. K. Crooks  
Electrical Engineering Division

RKC/rf  
Enc. (6)

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R E S E A R C H   F O U N D A T I O N

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## FOURTH PROGRESS REPORT

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THE DEVELOPMENT OF A HIGH-LEVEL,  
DIRECTIONAL, UNDERWATER-SOUND  
SOURCE USING EXPLOSION-INDUCED  
SHOCK WAVES

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E. G. Thurston, W. H. Peake, D. Ensminger,  
H. E. Trumbull, and J. H. Duffin

B. A. Landry and R. K. Crooks,  
Division Chiefs

February 1, 1954

### INTRODUCTION

This is the fourth progress report on Contract Nonr 903-(00), the purpose of which is to investigate the development of a high-level, underwater-sound source using explosion-induced shock waves. This report covers research performed between May 1, 1953, and August 1, 1953.

No experimental work was done between August 1, 1953, and January 4, 1954, pending the receipt of the contract authorizing the extension of the project.

The investigation has been concerned, first, with developing a Primacord-activated projector; second, with the development of a detonation tube in which gas mixtures are used as the source of explosive energy; and third, with the construction of a test float suitable for determining the performance of these devices.

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Previous quarterly reports have described in detail the progress in the development of the firing units. It is the purpose of this report to summarize the accomplishments of the contract year and to describe plans for future activity.

## SUMMARY

The floating measurement facility has been completed and is located on a lake formed by an abandoned quarry about 26 miles from Columbus. This lake is approximately 900 by 1800 feet and has a water depth of from 30 to 55 feet, depending on seasonal conditions. The relatively long round-trip range (over 1000 yards), the vertical stone walls, and the specialized equipment provided, such as a rapid-writing-rate oscilloscope and camera and specially designed triggering and delay circuits, make this test facility ideal for echo and attenuation measurements.

The unit using Primacord as the source of explosive shock waves was tested. Some mechanical difficulties were encountered, but they are not basic and steps are being taken to correct them. A peak sound-pressure level of approximately 150 decibels referred to 1 dyne per square centimeter, at a distance of 1 meter on the axis of the projector, has been obtained, this fulfills the specified design requirement of "equal to or greater than 145 db".

A system using pressure-activated switches and a hydrophone has been devised for the measurement of both the propagation velocity of the detonation wave tube and the pressure of the shock wave transmitted into the water at the immersed end. Preliminary measurements using an equivolume mixture of oxygen and acetylene have indicated velocities of about 10,900 feet per second and peak pressures of approximately 136 decibels referred to 1 dyne per square centimeter at 6 inches from the end of the tube end. The latter measurement is open to some question of interpretation and will be discussed in detail on page 15.

## THE UNDERWATER-SOUND-MEASUREMENT FACILITY

The facility consists of an enclosed structure, 20 feet by 40 feet, resting on two 60-foot pontoons, and having a central well of 4 feet by 30 feet. Figures 15 and 16 are exterior views of the structure; Figure 17 shows an interior view. The flooring runs the entire length of the pontoons, and, thus, provides a fore and aft deck, each 10 feet wide.

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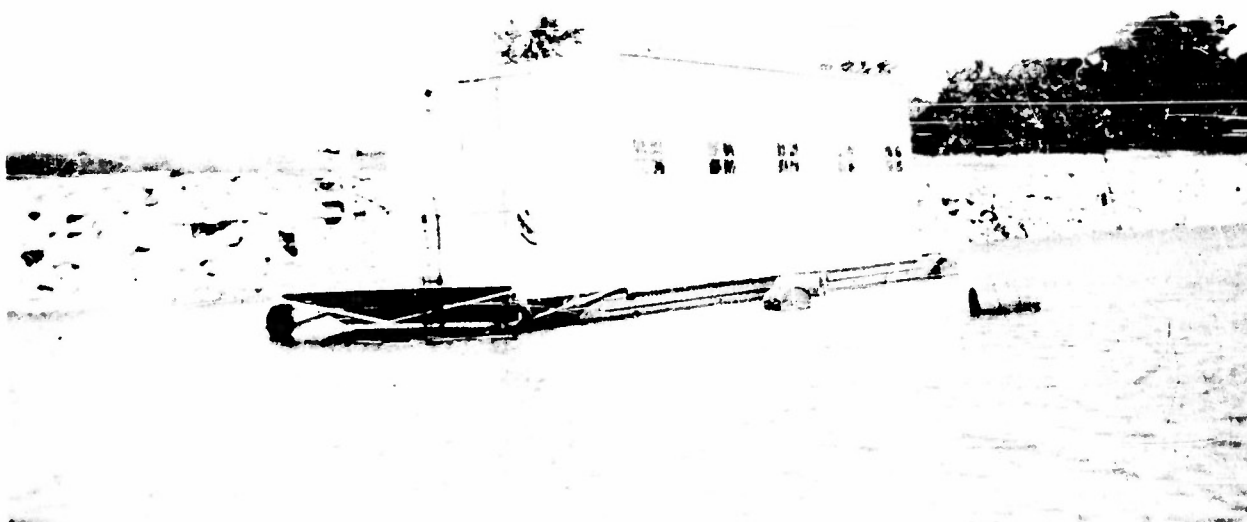


FIGURE 15. TEST FLOAT



FIGURE 16. FLOAT AND CABLE BUOYS AS SEEN FROM EAST BANK OF QUARRY

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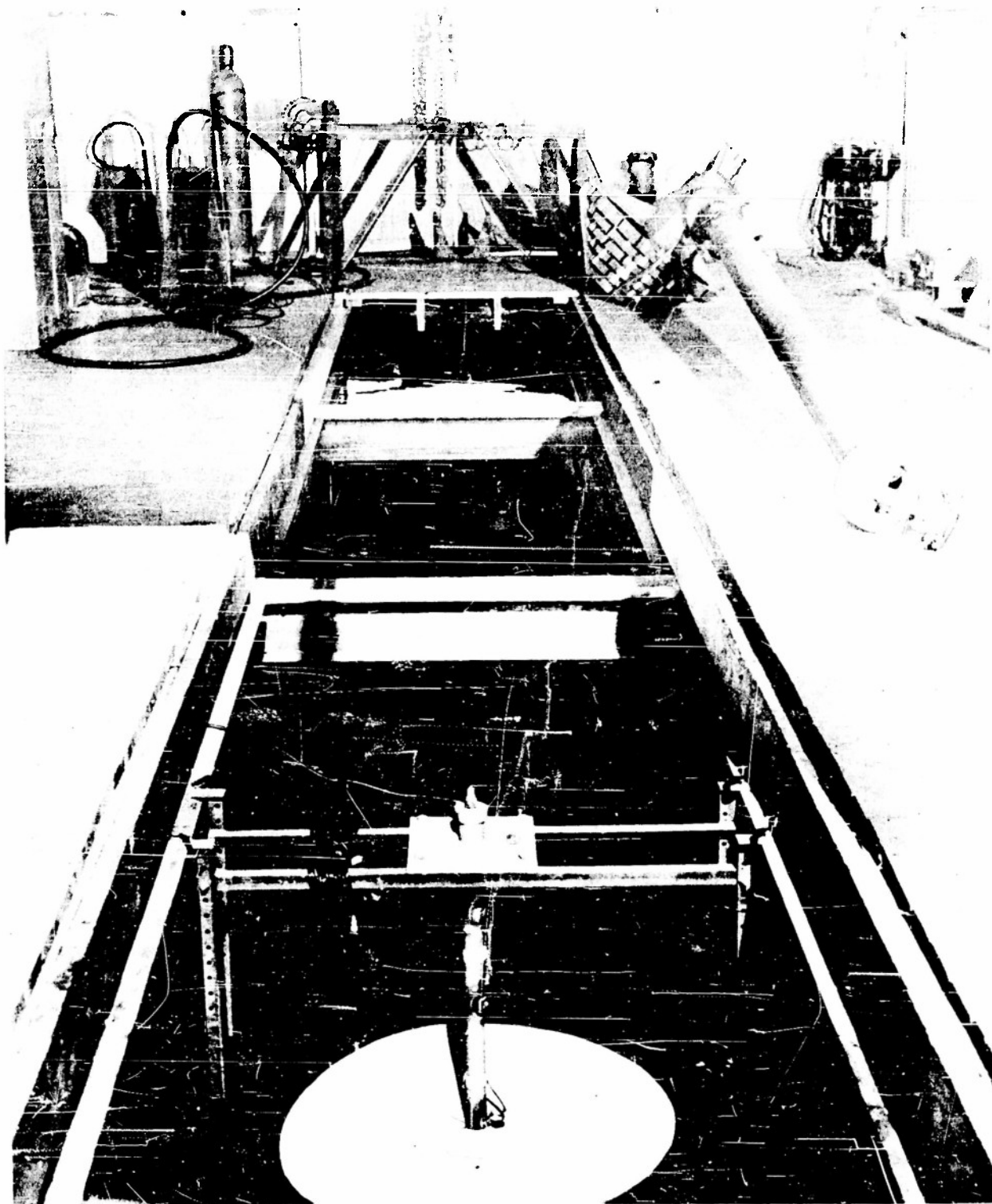


FIGURE 17. INTERIOR OF TEST FLOAT

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On three sides, the lake is bounded by vertical stone walls, which provide the good reflecting surfaces needed for echo ranging. The greatest available range exceeds 1000 yards, round trip. As shown in Figure 18, the fourth side provides a more gradual approach to the water, suitable for use by amphibious vehicles.

At the present time, the anchors for the pontoons are not adequate, as they are simply steel drums filled with concrete. Regulation anchors have been received and will be installed in the near future.

## Test Instrumentation

The special delay circuit mentioned in the Third Progress Report as being at the design stage was completed, but it has not been evaluated completely.

Since the driver for the calibrating projector has not been received yet, it has not been possible to calibrate the Brush EM-110 hydrophones. Thus, although one of these units has served adequately as the triggering hydrophone, an Atlantic Research Company hydrophone, Model EC-31, has been used as the pickup unit, until the Brush units can be calibrated.

The Dumont high-writing-rate oscilloscope and Polaroid Land Camera combination have given satisfactory results when used to record pulses from the Primacord unit and the detonation tube (see, for example, Figures 19, 23, and 24).

## PRIMACORD SOUND GENERATOR

### Operational Difficulties

The design of the primacord unit was described in the Second Progress Report. When the unit finally was tested under water, a number of difficulties were encountered.

### Firing Pin

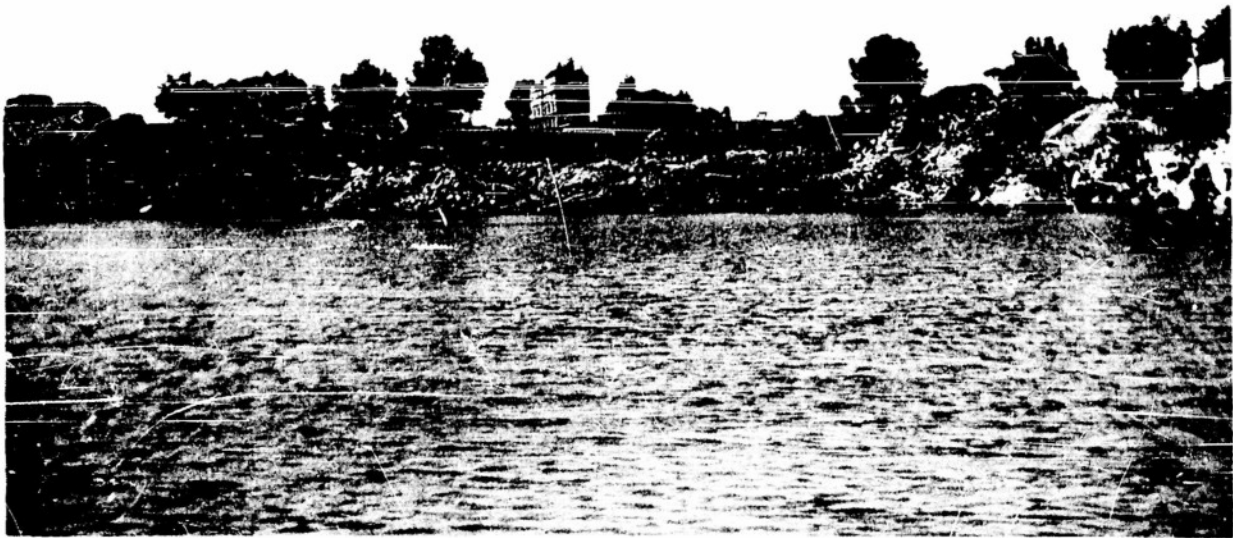
The most serious difficulty was found to be breakdown of insulation around the firing pin. In the first model the large forces resulting from the

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**FIGURE 18. NORTH BANK APPROACH TO THE QUARRY LAKE**

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explosion spread the insulating bushing so that the firing pin jammed in the nozzle. In an attempt to avoid this spreading, a pin was made which fitted inside a nylon bushing which, in turn, was enclosed coaxially in a metal sleeve. This second model also failed, as the pin was driven through the end of the insulating bushing. Other models were constructed, but these also failed because of shearing of the contact leads.

Thus, sufficient difficulty was encountered with this general type of design that a new approach has been taken, the details of which are given in the section on Future Work Plans.

## Loading Mechanism

Occasional jamming occurred in the loading mechanism. This was found to be due to overlong cartridges.

## Ammunition Guides

The force of the explosions caused undue expansion and tearing of the cartridge guides. These were removed. The charges were found to center quite well on the axis of the reflection rings without these guides.

## Test Results

Unfortunately, the difficulties described above were sufficient to prevent adequate and conclusive testing within the short interval between completion of construction work and the end of the contract period. Thus, it was not possible to obtain enough repetitive firings to adjust the delay circuits properly. In the few photographs obtained, of which Figure 19 is typical, self triggering of the oscilloscope was employed. However, some tentative conjectures can be made on the basis of these results.

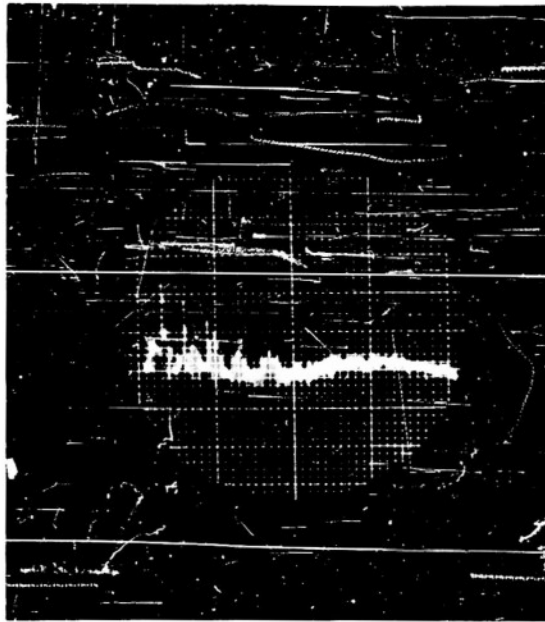
If a direct correspondence is assumed between hydrophone output voltage and sound-pulse amplitude and waveform, the peak sound pressure measured on the projector axis, at 30 feet, is approximately 130 decibels referred to 1 dyne per square centimeter. This assumption, however, must be viewed with some caution because of the possibility that the response of the water-loaded hydrophone is not sufficiently flat in the frequency range of interest. Nevertheless, the proposed design objective of 145 decibels referred to 1 dyne per square centimeter, at a distance of 1 meter, assuming spherical divergence, was based on the preliminary work at Orlando Sound Reference Laboratory, and examination of their measurement conditions manifests the presence of the same problems in interpretation. Assuming

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Sweep rate — 200 microseconds per inch

Sensitivity — 10 volts per inch

Ten small divisions equal 1 inch

FIGURE 19. OSCILLOGRAM OF HYDROPHONE OUTPUT WHEN EXCITED BY WAVETRAIN AT 30 FEET FROM PRIMACORD UNIT

that the hydrophone used at Orlando had essentially the same frequency characteristics, it can be said that the value of approximately 150 decibels, at a distance of 1 meter, as indicated by our measurements, is in excess of the design requirements in a relative, if not an absolute, sense.

The time spacing of the first three pulses is smaller than that expected from the design. The design value of pulse displacement, based on a nominal value for the velocity of sound of 60,000 inches per second and a difference in path length between rings of 5 inches, would be about 83 microseconds. The spacing of the first three voltage pulses is about 65 microseconds, whereas the spacing between the third and fourth is about 85 microseconds (actually, at least the first sound pulse probably is not recorded). It can also be noted that the amplitude of successive pulses decreases, which is not what one might expect at first thought, if one considered the problem from the point of view of small-amplitude theory. In that case, in the vicinity of the line charge, the sound-pulse intensity would vary inversely as the radial distance. However, since the area of each ring varies directly as the radial distance, the amounts of energy reflected from all the rings should be the same, assuming that the fraction of the energy incident upon each ring that is reflected by the ring is proportional to the area of the ring. If this assumption is true, the pressure amplitudes of all the sound pulses in the far field also should be the same. These disparities can be reconciled tentatively if one assumes extreme shock-wave conditions within the ring-cone projector, for then the theory of finite amplitudes suggests both a higher velocity and an anomalous attenuation.

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Some further evidence for this supposition is given by the fact that the pulses appear at increasing intervals as their amplitude decreases. In fact, the interval between the third and fourth pulses is that which is expected from the design. Another reason for the amplitude of the successive pulses not being the same could be that the above assumption regarding the fraction of energy reflected by the rings is not true. The assumption is true only if the major portion of the energy of the incident pulse is contained in frequency components whose wavelengths are much less than the smallest dimension (the width) of the rings. If this is not so, the reflection coefficients would depend upon the shapes and diameters of the rings, as well as on their areas.

Furthermore, Cole<sup>(1)</sup> indicates a change in pressure dependence from  $(a_0 r)^{-0.6}$  to  $(a_0 r)^{-1.15}$  at a radial distance equal to about half the charge length, that is, a change from roughly cylindrical to roughly spherical divergence. Here,  $a_0$  is the radius of the charge and  $r$  is the distance from the axis. Since the charge length is only 1 foot, this could allow such a change to occur at a radius of about 6 inches. This would tend to reduce disproportionately the intensity at the surface of the larger rings. Cole further points out that an increase in pressure can be expected toward the far end of a line charge relative to that existing near the detonated end. In general, such shock waves appear to have axial symmetry, in which both distances along the axis and the radius from the axis determine the behavior of the system, rather than circular symmetry, where radial distance is the only significant variable. This tendency is in accord with our observations.

It would appear that all these hypotheses also demand a change in the character of the wave after reflection from the rings such that the aforementioned behavior will exist only before reflection. This requirement also appears somewhat plausible because the geometrical intensity dependence of the wave changes from an inverse-first-power to an inverse-square law.

The Orlando Sound Reference Laboratory measurements indicated equal amplitudes. There are several factors which may account for this. Among these are limitations in the recording system, differences in size or shape of the reflecting rings, producing a closer approach to specular reflection, and possibly a closer approach to a line source due to more rapid propagation of the explosion wave in the charge. These factors should be investigated in our system.

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(1) Cole, Robert H., Underwater Explosions, Princeton University Press (1948), p 129.

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## DETONATION TUBE

### Test Apparatus

The detonation tube and its associated gas-mixing apparatus remain essentially as described in the previous progress report. The firing mechanism was modified by replacing the original Ford spark coil by a high-voltage neon transformer, a change which greatly improved firing reliability.

Figure 20 shows the tube mounted in the well of the measurement facility for testing. The round metal disk is to prevent spraying of the contacts.

### Measurement System

A schematic drawing of the measurement system used with the detonation tube is shown in Figure 21. This consists of three simple, pulse-generating circuits. One of these is a trigger circuit used to initiate the oscilloscope sweep when the shock wave actuates the switch, SW<sub>1</sub>, as the wave passes down the tube. The other two circuits generate a pulse as the wave traveling down the tube actuates switches SW<sub>2</sub> and SW<sub>3</sub>. These pulses, together with the output of the hydrophone, are displayed on the y-axis of the oscilloscope.

The development of the switches required special attention. (See Figure 22.) After consideration of other designs, including an ionization-type probe, it was decided that a pressure-actuated switch of conventional design would meet the requirements best. The rather severe operating conditions make the selection of a suitable diaphragm material of significance. Two types of spring metal, a 5-mil-thick phosphor bronze diaphragm and an Elgiloy diaphragm, are in use and appear to be satisfactory.

### Test Results

To date, all tests have been made with equivolume mixtures of acetylene and oxygen. Figure 23 shows a typical oscillogram obtained by using the system described above. The two marker pips indicate a propagation velocity of about 11,000 feet per second. (The average value of a series of such measurements is 10,900 feet per second.) The probable error for this particular set of measurements is about  $\pm 3$  per cent of the

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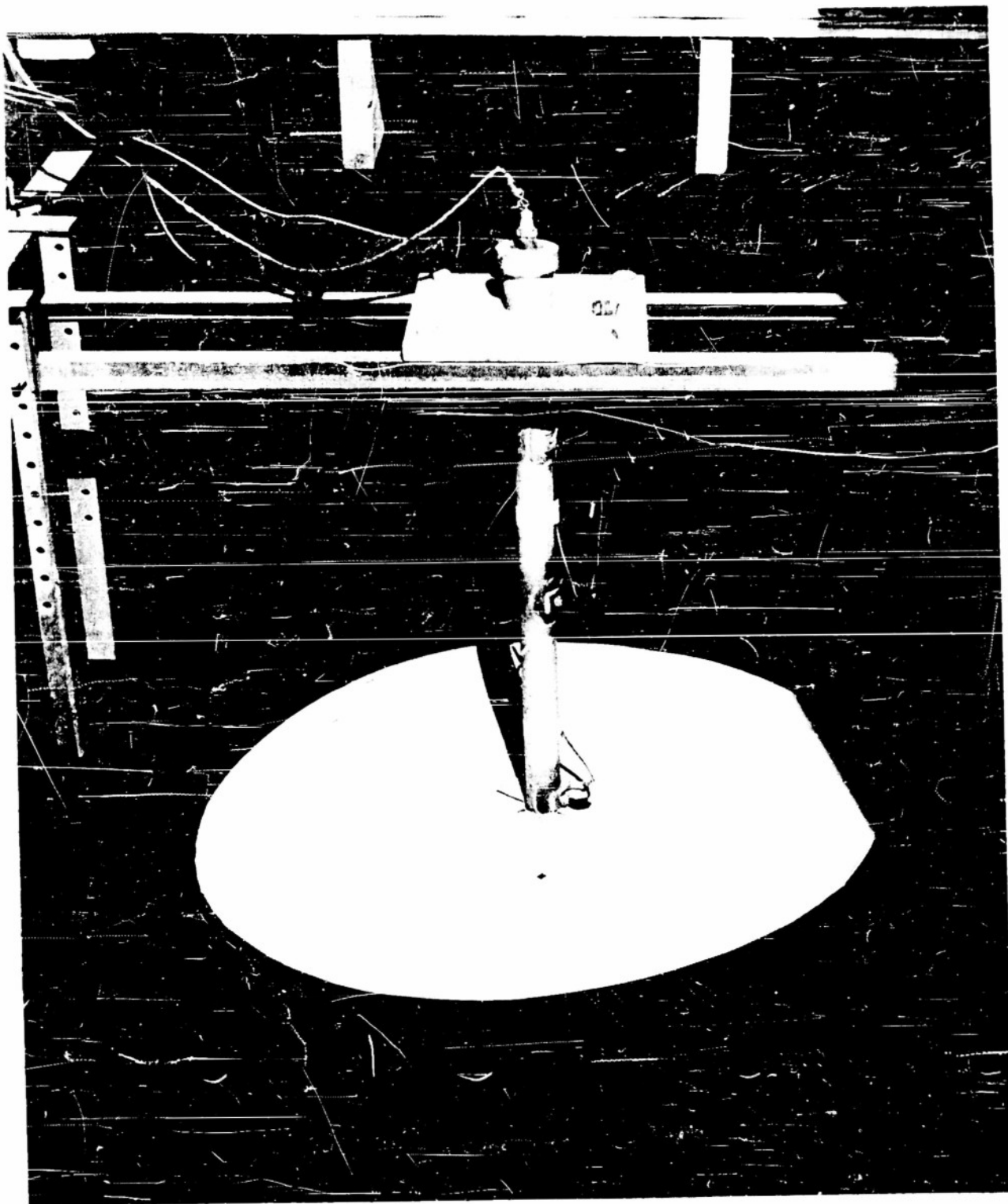


FIGURE 20. DETONATION TUBE MOUNTED IN WELL OF THE MEASUREMENT BARGE

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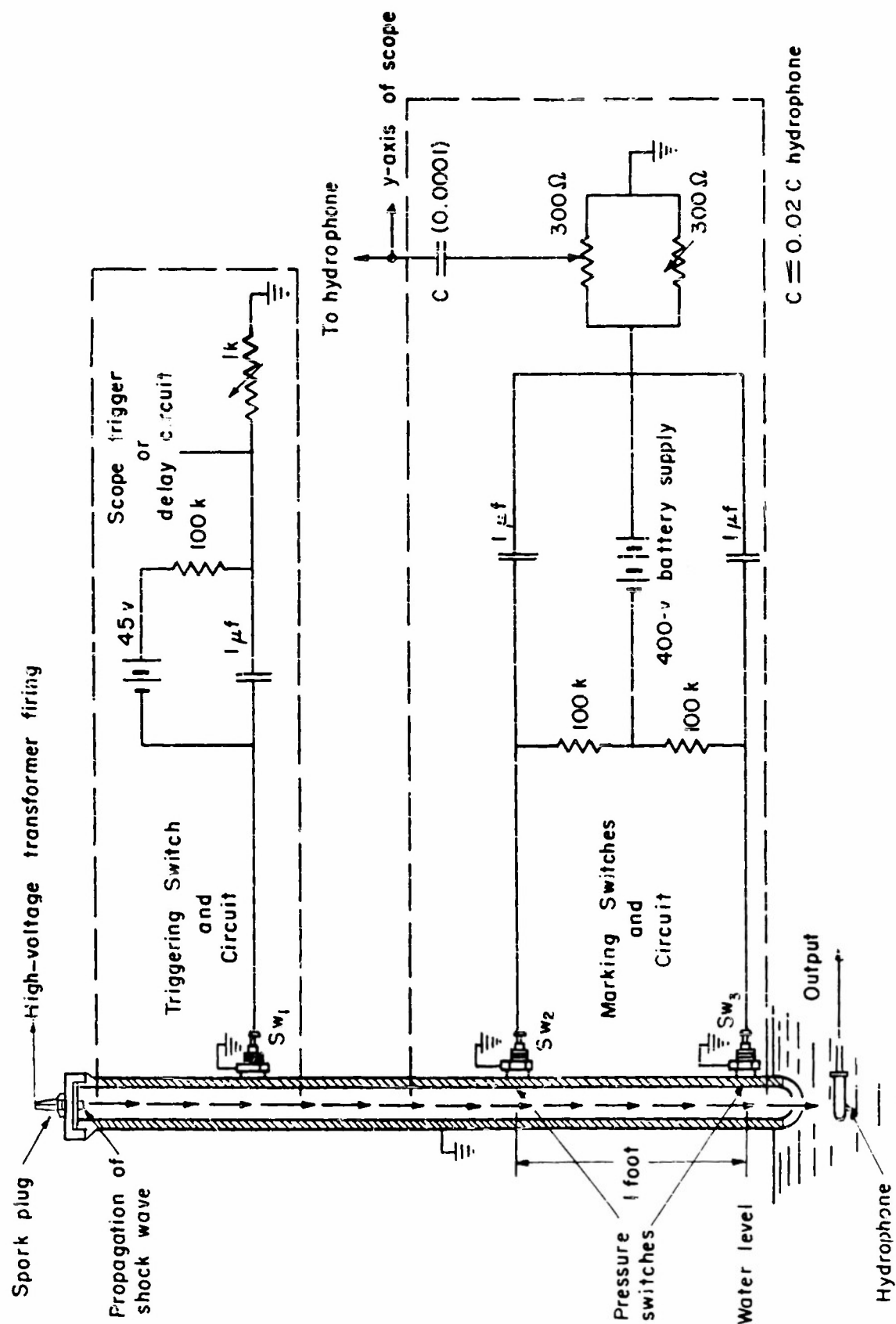


FIGURE 21. TRIGGERING AND MARKING SWITCHES AND ASSOCIATED CIRCUITS

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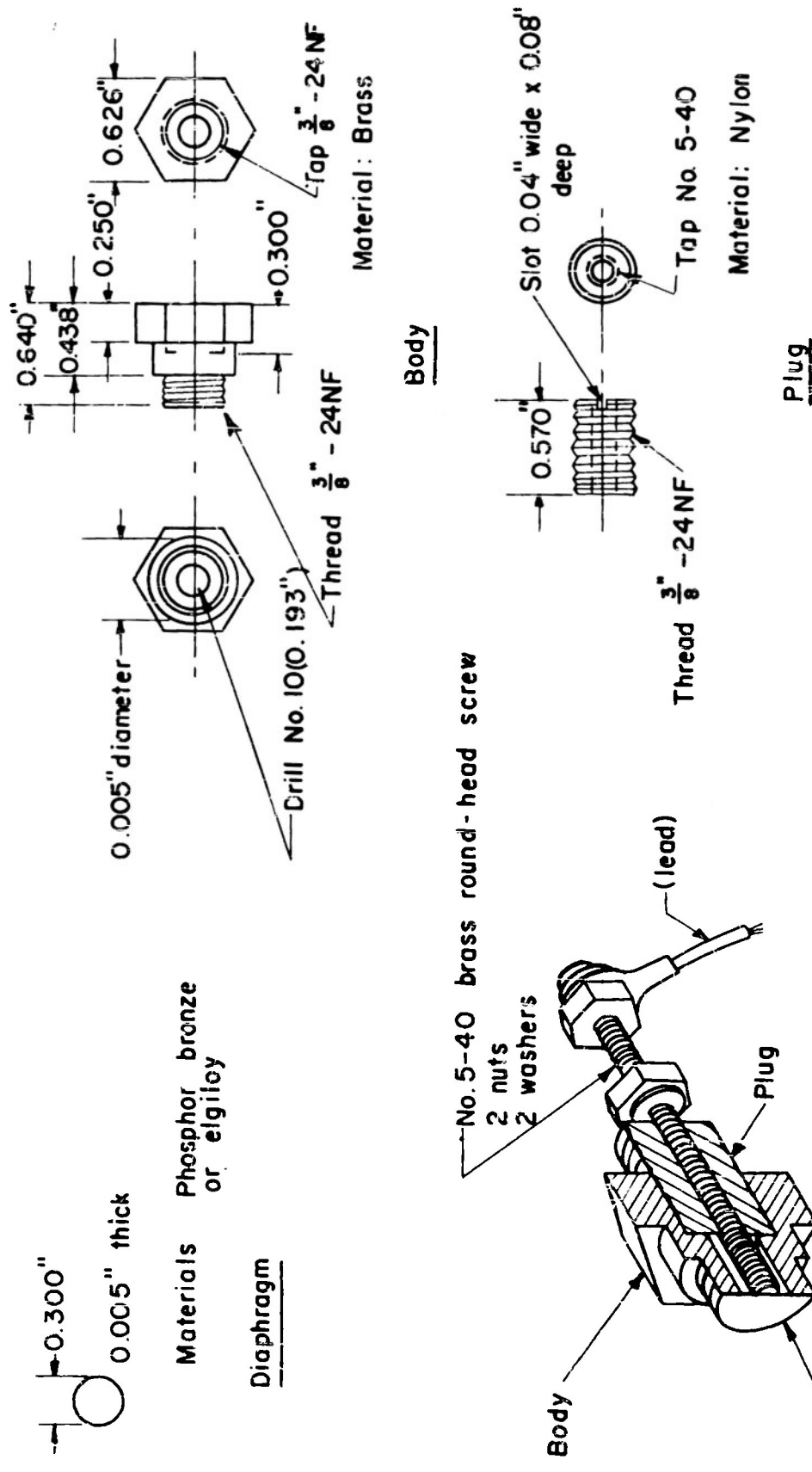


FIGURE 22. PRESSURE SWITCH

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Sweep rate — 100 microseconds per inch

Sensitivity — 20 volts per inch

Ten small divisions equal 1 inch

FIGURE 23. OSCILLOGRAM OBTAINED WITH DETONATION-TUBE MEASUREMENT SYSTEM SHOWING MARKING PIPS AND HYDROPHONE OUTPUT

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actual propagation velocity, but the method should be capable of about 1 per cent accuracy if the full sweep width is utilized for marking pips alone.

Unfortunately, the output of the hydrophone cannot be interpreted unequivocally as indicative of the true nature of the shock wave in either amplitude or wave form. A critical examination of a typical trace shown in Figure 24, which is an expanded picture of the hydrophone output voltage, reveals that the dominant frequency is close to that which is to be expected for the resonant frequency of the water-loaded hydrophone. This indicates that the hydrophone is ringing under shock excitation and, therefore, it is extremely difficult to correlate the response with the excitation without previous knowledge of the exact nature of the shock wave. This seems to be a general difficulty in recording and interpreting underwater shock-wave data, due to the extreme difficulty of constructing a hydrophone with a resonant frequency high enough to avoid this effect.

## FUTURE WORK PLANS

### Underwater-Sound-Measurement Facility

#### Test Float

No immediate changes are planned for the test float except to provide more adequate anchors to prevent excessive drifting. These have been procured as GFE.

#### Test Instrumentation

Further development work will proceed with the special delay circuit. The Brush BM-110 hydrophone will be calibrated.

#### Primacord Sound Generator

Initial work is planned to overcome the difficulties described previously.

#### Firing Pin

A new design is planned for the firing system as shown in Figure 25. In this system, the firing pin, 1, will be grounded. This will avoid

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Sweep rate — 25 microseconds per inch

Sensitivity — 20 volts per inch

Ten small divisions equal 1 inch

FIGURE 24. EXPANDED PICTURE OF HYDROPHONE OUTPUT WHEN EXCITED BY  
SOUND PULSE FROM DETONATION TUBE

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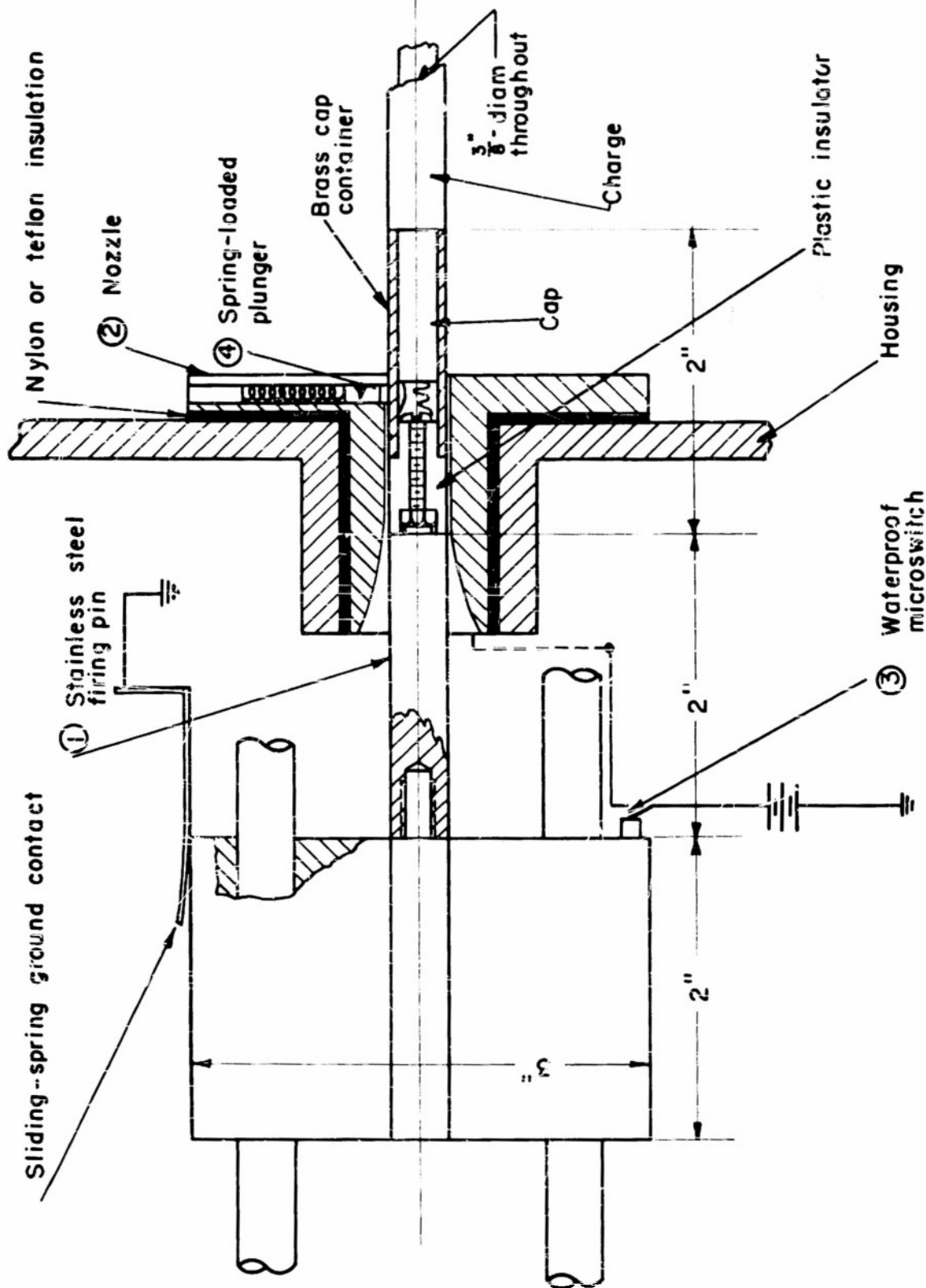


FIGURE 25. PROPOSED FIRING ASSEMBLY

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entirely the need for insulation materials in this part and will eliminate shorting and allow much more rugged construction. Then the "hot" contact will be made to the sides of the firing-cap case through the nozzle, 2, which will be insulated electrically from the rest of the case. The certainty of this contact will be assured by several spring-loaded plungers, 4, which will also help to center the charge along the axis of the projector. A microswitch, 3, will allow the circuit to be energized only when the charge is in position for firing. This will promote proper timing in the firing cycle and also prevent rapid battery discharge due to continuous leakage current through the water.

## Loading Mechanism

Jamming of the loading mechanism will be eliminated by careful sizing of the charges and caps to uniform length. The cap and charge will also be constructed as an integral unit to facilitate this length control.

## Primacord Guides

It is believed that the spring-loaded plungers in the nozzle and the integral cap-charge construction will allow suitable loading without further guiding. However, several support arrangements for the free end of the charge are under consideration.

## Performance Tests

When the Primacord unit is functioning properly, a series of performance tests will be made. These will include directivity patterns, amplitude variation with distance from the projector (say, 5 to 50 feet), echo and long-range attenuation measurements, and extended repeated-firing, reliability trials. These tests should also permit evaluation of the new delay and switching circuit and provide data to evaluate the hypothesis advanced earlier in the report to explain the observed behavior.

## Preparation for Sea Test

Moderate effort will be expended to prepare the unit for sea test. This will include treatment to increase corrosion resistance and any other reasonable changes believed necessary to assure reliable, convenient, and safe operation under these conditions. Personnel from the Naval Laboratory where such tests will be held will be consulted in this regard.

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## Detonation-Tube Research

This program is planned to optimize as far as possible the design of this device. It will include the following studies:

- (1) Study of various mixtures of acetylene and oxygen
- (2) Study of the effects produced by mixtures of other gases
- (3) Study of the effect of other system parameters, such as tube length, tube diameter, immersion depth, etc.
- (4) Design of a tube of optimum dimensions based on the results of the preceding studies
- (5) Measurement of the radiation pattern of such a tube
- (6) Design of a suitable reflector based on the nature of the measured radiation pattern of the tube and the directionality characteristics and pulse-repetition rate desired in the completed unit
- (7) Measurement and test of the final experimental unit.

Data on which this report is based are found in BMI Laboratory Record Books Nos. 6360, pages 1 through 14; 7348, pages 1 through 53; and 7769, pages 1 through 23.

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